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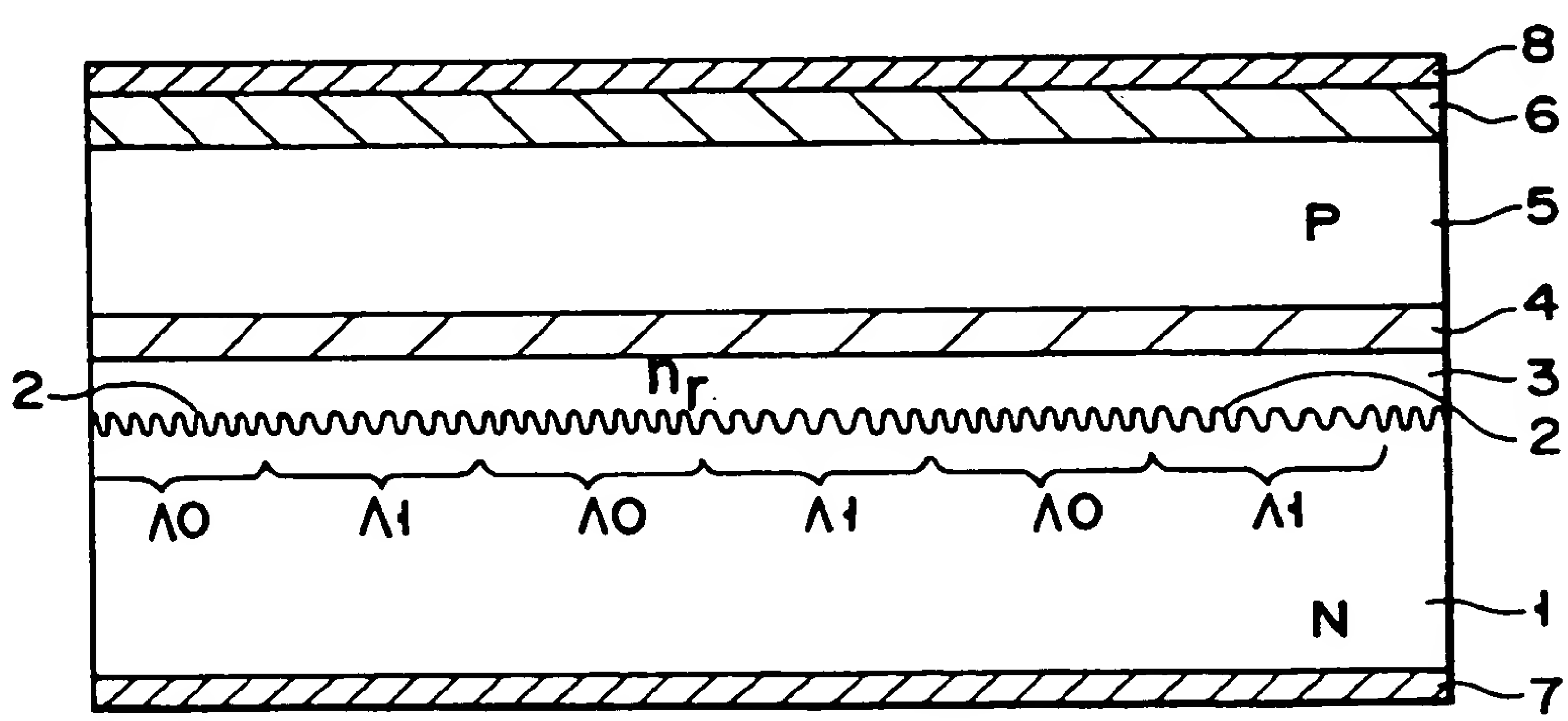
(54) Distributed feedback semiconductor laser.

(57) A distributed feedback semiconductor laser includes a diffraction grating (2) having a plurality of different pitches (Λ0, Λ1). Altough it is a multi mode laser, an oscillating mode having a longitudinal single mode characteristic is obtained. The distributed feedback semiconductor laser is thus free from nonlinear characteristics but has low-noise characteristics.



F I G. 6

The present invention relates to a distributed feedback semiconductor laser used for optical fiber communications or the like.

As is well-known, in optical fiber communications, an optical signal generated by modulating a light emitting element such as a semiconductor laser is transmitted through an optical fiber. A longitudinal single mode semiconductor laser is used for long-distance transmission in order to prevent the semiconductor laser from being deteriorated by dispersion of the optical signal in the optical fiber. A longitudinal single mode semiconductor laser having good low-noise characteristics is used in an analog multichannel image transmission such as cable television.

The longitudinal single mode semiconductor laser is embodied by a distributed feedback (referred to as DFB hereinafter) semiconductor laser. As shown in Fig. 1, the DFB semiconductor laser comprises a diffraction grating 22 formed on a semiconductor substrate 21, a wave guide layer 23, an active layer 24, a clad layer 25, and a contact layer 26. A bias current I_t is supplied to electrodes 27 and 28 between which the substrate 21, grating 22, and layers 23-26 are interposed, to inject the current into the active layer 24. The active layer 24 is thus oscillated and, as shown in Fig. 2, a single wavelength λ, which depends upon a pitch P of the diffraction grating 22, and composition and dimension of the wave guide layer 23 and active layer 24, can be obtained.

According to the DFB semiconductor laser having the above structure, photons and electrons in the wave guide layer 23 and active layer 24 interact with each other only in the single wavelength mode. Therefore, the distribution of internal electric field is strongly influenced by conditions such as pitch P of the diffraction grating 22, refractive index of the wave guide layer 23, and dimension and precision of the active layer 24 and wave guide layer 23. If the conditions are not optimal, an extremely nonlinear output (kink) characteristic or a multi-wavelength oscillation appears in accordance with the density of the injected current. In Fig. 3, samples #1 and #4 show normal characteristics, but samples #2 and #3 show kink characteristics. As a result, there occurs problems of decrease in yield and reliability. Although the longitudinal single mode semiconductor laser having the low-noise characteristic and the low-distortion characteristic is the most suitable for the analog multichannel video transmission, it has the problem of kink characteristic.

Fig. 4 is a cross sectional view showing a structure of a Fabry-Perot (referred to as FP hereinafter) semiconductor laser. As shown in Fig. 4, an active layer 34, a clad layer 35, and a contact layer 36 are formed in sequence on a substrate 31, and these layers and substrate are interposed between electrodes 37 and 38. Mirror reflecting surfaces 39a and 39b are formed on both facets of the FP semiconductor laser. Reference character L denotes length of the resonator. Fig. 5 shows power spectrum of the FP semiconductor laser. Since the FP semiconductor laser has no diffraction grating and photons and electrons interact with each other in a plurality of modes, the FP semiconductor laser is excellent in the linearity in light emitting characteristic and thus suitable for analog modulation. However, the interaction of electrons and photons in a plurality of modes causes mode partition noises, and the relative intensity of noise (RIN) of the FP semiconductor laser is greater than that of the longitudinal single mode semiconductor laser by about 20 dB. Thus FP semiconductor laser cannot be used in analog applications.

As described above, in the conventional longitudinal single mode semiconductor laser having low-noise characteristic and low-distortion characteristic, photons and electrons in the active layer and wave guide layer interact with each other only in the single wavelength mode, so that the distribution of internal electric field is strongly influenced by the pitch of diffraction grating and the dimension and precision of the active layer and wave guide layer.

It is accordingly an object of the present invention to provide a highly reliable DFB semiconductor laser which has low-noise and low-distortion characteristics and, which can prevent a multi-wavelengths oscillation from being generated.

According to an aspect of the present invention, there is provided a DFB semiconductor laser, comprising an active layer formed on a semiconductor substrate, and a wave guide layer having a band gap larger than that of the active layer and having a diffraction grating formed in parallel with the active layer, the diffraction grating having a plurality of different pitches, being formed in a direction of guided waves, and having a plurality of oscillation wavelengths within a region having a predetermined length.

According to another aspect of the present invention, there is provided a DFB semiconductor laser, comprising an active layer formed on a semiconductor substrate, and a wave guide layer having a band gap larger than that of the active layer and having a diffraction grating formed in parallel with the active layer, a pitch of the diffraction grating being expressed as follows:

$$\Lambda m = \frac{\lambda \ (2n_r L \pm m\lambda)}{4{n_r}^2 L}$$

where

Λm : pitch of diffraction grating

n_r : effective refractive index of wave guide layer.

L : length of resonator (cavity length)

m : positive integer

λ : oscillation wavelength,

and the diffraction grating having a region having a predetermined length and being formed in a direction of guided waves.

According to still another aspect of the present invention, there is provided a DFB semiconductor laser, comprising an active layer formed on a semiconductor substrate, and a wave guide layer having a band gap larger than that of the active layer and having a diffraction grating formed in parallel with the active layer, the diffraction grating having a plurality of different pitches and being formed in a direction of guided waves so as to generate a plurality of oscillation wavelengths having a wavelength interval which is same as a wavelength interval $\Delta\lambda m$ of a FP mode.

According to the present invention, the diffraction grating having a plurality of different pitches is formed to control the number of oscillating wavelength modes, reduce mode distribution noises, and improve nonlinear outputs.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a cross sectional view showing a structure of a conventional DFB semiconductor laser;

Fig. 2 is a view showing the oscillation wavelength of the semiconductor laser shown in Fig. 1;

Fig. 3 is a view for explaining the input current vs. output power characteristic of the semiconductor laser shown in Fig. 1;

Fig. 4 is a cross sectional view showing a structure of a conventional FP semiconductor laser;

Fig. 5 is a view showing the oscillation wavelength of the semiconductor laser shown in Fig. 4;

Fig. 6 is a cross sectional view showing a structure of a DFB semiconductor laser according to an embodiment of the present invention;

Fig. 7 is an end view showing a light emitting facet of the semiconductor laser shown in Fig. 6;

Fig. 8 is a view showing the oscillation wavelength of the semiconductor laser shown in Fig. 6;

Fig. 9 is a view for explaining the input current vs. output power characteristic of the semiconductor laser shown in Fig. 6;

Fig. 10A is a view showing the phase of a conventional FP mode of the DFB semiconductor later; and

Fig. 10B is a view showing the phase of a FP mode of the semiconductor laser of the present invention.

Embodiments of the present invention will be described with reference to the accompanying drawings.

Fig. 6 is a cross sectional view showing a structure of a DFB semiconductor laser according to an embodiment of the present invention. A diffraction grating 2 having pitches different from each other by predetermined lengths is formed on an N-type semiconductor substrate 1 which is doped with InP. A wave guide layer 3 doped with InGaAsP, an active layer 4, a P-type clad layer 5 doped with InP, and a P^+-type contact layer 6 doped with InGaAsP are formed in sequence on the diffraction grating 2. An electrode 7 is formed on the underside of the substrate 1, and an electrode 8 is formed on the contact layer 6. The pitches of the diffraction grating 2 have different values from the central value, as represented by the following equation.

$\Lambda = \lambda/2n_r$ (1)

where

Λ : pitch of diffraction grating

λ : wavelength

n_r : effective refractive index of wave guide layer 3.

If n_r = 3.7 is used when the oscillation wavelength of the semiconductor laser is in 1.3 μm band, then, according to the equation (1), the predetermined pitch length Λ_0 = 1770Å. In the embodiment shown in Fig. 6, the diffraction grating having the pitch Λ_1 = 1771.6Å and the diffraction grating having the pitch Λ_0 are alternately arranged 50 μm by 50 μm.

Fig. 7 is an end view showing a light emitting facet of the semiconductor laser shown in Fig. 6. The

width W of the active layer 4 and the wave guide layer 3 is about 1 µm to obtain a lateral single mode. Both sides of the active layer 4 and the wave guide layer 3 are optically and electrically blocked by an N-P type reverse junction blocking layer 9 of InP.

As shown in Fig. 8, the DFB semiconductor laser having the above structure has two wavelengths λ_1 - (1310 nm) and λ_2 (1311 nm), and the side mode suppression ratio of two oscillation modes is 35 dB or more. Since the interactions between photons and electrons are distributed into two modes, the nonlinear output characteristic of the DFB semiconductor laser is greatly improved, resulting in improvement in yield, as is apparent from samples #1 to #4 shown in Fig. 9. This can be done even though the pitch of the diffraction grating, and the dimensions of the active layer and wave guide layer do not meet the optimum conditions. Even if the suppression ratio is 30 dB, the dispersion of optical signals in long-distance transmission is hardly affected adversely since a wavelength interval between the two oscillation modes is 1 nm.

In the above embodiment, the pitch of diffraction grating is 1.3 µm; however, the same effect can be obtained even if it is 1.55 µm. In this case, a buffer layer can be formed on the active layer 4 when the need arises. The diffraction grating 2 can also be formed on the active layer 4. In the above embodiment, the diffraction grating 2 is formed so that its two pitches are alternately changed 50 µm by 50 µm. However, the present invention is not limited to 50 µm pitch and the pitches can be changed at an equal rate, at an inequable rate, or in arbitrary order. The number of pitches of the diffraction grating is not limited to two but can be three or more.

A DFB semiconductor laser according to another embodiment of the present invention will be described with reference to Fig. 6.

A low-noise multi mode semiconductor laser is ideal for the analog multichannel image transmission from the viewpoint of a tolerance for return light. When a high reflectance film is deposited on the facets of the DFB semiconductor laser to obtain an output of a high output, the DFB semiconductor laser include a Fabry-Perot mode output. In the DFB semiconductor laser, therefore, it is only necessary to arrange a plurality of pitches of a diffraction grating which causes a plurality of oscillation wavelengths (see Fig. 8) having the same wavelength interval as $\Delta\lambda m$ of the Fabry-Perot mode. The wavelength interval $\Delta\lambda m$ of the Fabry-Perot mode is expressed by the following equation.

$$\Delta\lambda m = \lambda^2/2n_r \cdot L \qquad (2)$$

where

$\Delta\lambda m$: wavelength interval
n_r : effective refractive index of wave guide layer
λ : wavelength
L : length of resonator (cavity length)

The pitch Λm of diffraction grating is given by the following equation.

$$\Lambda m = \frac{\lambda \pm m\Delta\lambda m}{2n_r} \qquad \ldots (3)$$

Substituting the equation (2) for the equation (3), the pitch Λm is expressed by the following equation.

$$\Lambda m = \frac{\lambda(2n_rL \pm m\lambda)}{4n_r{}^2L} \qquad \ldots (4)$$

(m is an integer)

A diffraction grating having three kinds of pitches is formed under the condition that the central pitch is Δ_0 and m = 1. The diffraction grating is formed with the pitch Λ_0 between pitches Λ_1. If the wavelength λ is 1310 nm, the pitches of the diffraction grating are Λ_0 = 1770Å, and Λ_1 = 1771.3Å and 1769.2Å.

Since the DFB semiconductor laser having the above-described structure has three oscillation modes, the DFB mode coincides with the FP mode having three or four main oscillation modes. Fig. 10A shows a phase difference between an output of the DFB mode and that of the FP mode, and Fig. 10B shows a phase coincidence between them. The DFB laser is not therefore influenced by a variation in phase due to the reflection of wave on the facet of a resonator. Since the photons and electrons interact with each other

in three modes, the nonlinear output characteristic such as a kink can hardly be obtained. Further, the mode can hardly be distributed since a gain is specified by the diffraction grating, and a high relative intensity of noise peculiar to the FP semiconductor laser is improved.

In the above embodiment, the wavelength λ is 1310 nm. However, it can be set to 1550 nm or the other value. Although three oscillation modes are used in the embodiment, the same effect can be obtained if the number of the modes is two or more. The refractive index of the facet of the resonator can be set at an arbitrary value.

As described above, according to the present invention, since a diffraction grating having different pitches, an oscillation mode having a longitudinal single mode characteristic can be obtained although it is a multi mode. A DFB semiconductor laser having no nonlinear characteristic but low-noise characteristic can thus be provided.

Claims

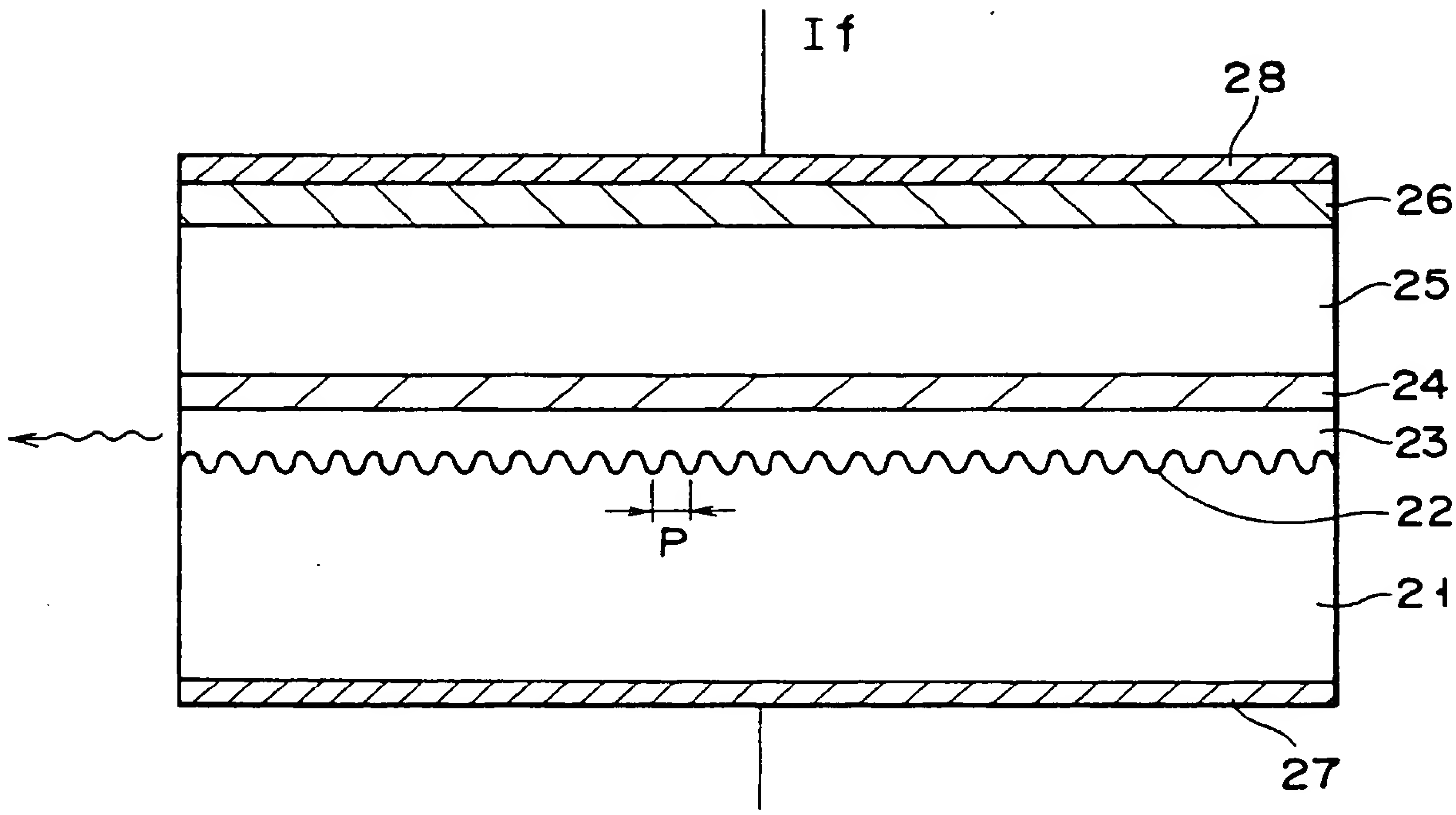
1. A distributed feedback semiconductor laser comprising:
   an active layer (4) formed on a semiconductor substrate (1); and
   a wave guide layer (3) having a band gap larger than that of said active layer (4) and having a diffraction grating (2) formed in parallel with said active layer (4),
   said diffraction grating (2) having a plurality of different pitches ($\Lambda 0$, $\Lambda 1$), being formed in a direction of guided waves, and having a plurality of oscillation wavelengths within a region having a predetermined length.

2. A distributed feedback semiconductor laser comprising:
   an active layer (4) formed on a semiconductor substrate (1); and
   a wave guide layer (3) having a band gap larger than that of said active layer (4) and having a diffraction grating (2) formed in parallel with said active layer (4),
   a pitch of said diffraction grating (2) being expressed as follows:

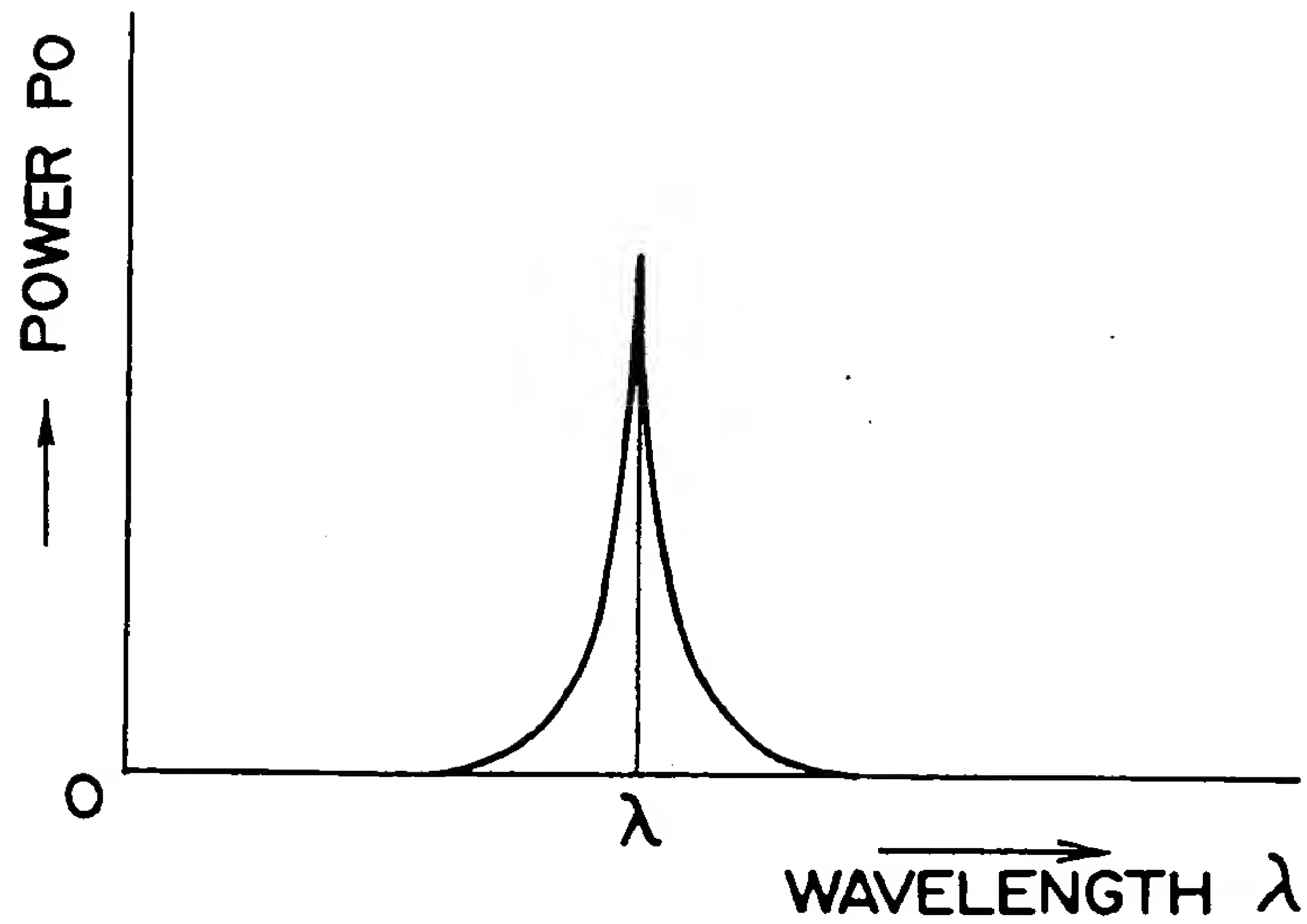
$$\Lambda m = \frac{\lambda(2n_rL \pm m\lambda)}{4{n_r}^2L}$$

   where
   Λm : pitch of diffraction grating
   n_r : effective refractive index of wave guide Layer
   L : length of resonator (cavity length)
   m : positive integer
   λ : oscillating wavelength,
   and said diffraction grating (2) having a region having a predetermined length and being formed in a direction of guided waves.

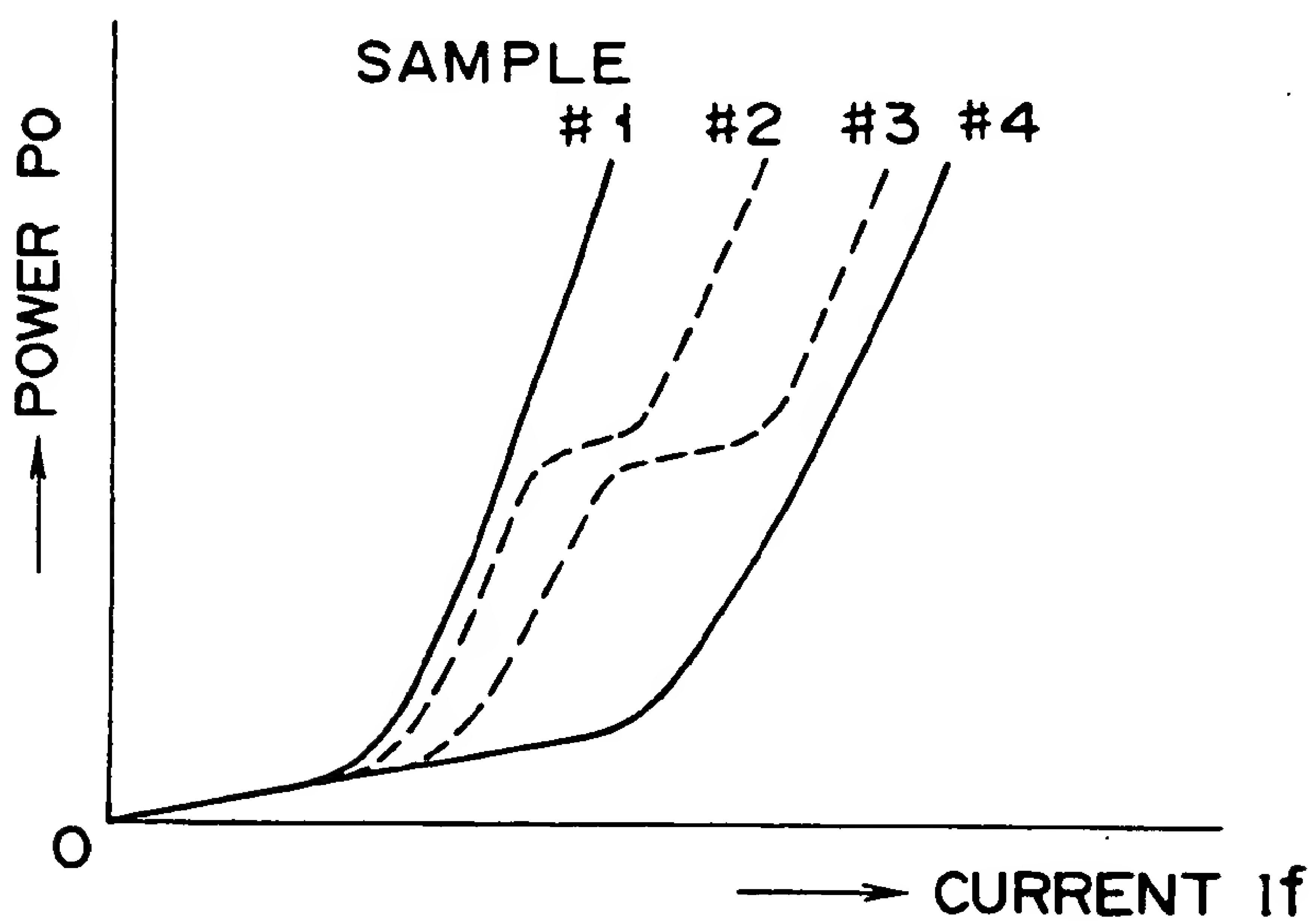
3. A distributed feedback semiconductor laser comprising:
   an active layer (4) formed on a semiconductor substrate (1); and
   a wave guide layer (3) having a band gap larger than that of said active layer (4) and having a diffraction grating (2) formed in parallel with said active layer (4),
   said diffraction grating (2) having a plurality of different pitches ($\Lambda 0$, $\Lambda 1$) and being formed in a direction of guided waves so as to generate a plurality of oscillation wavelengths having a wavelength interval which is same as a wavelength interval $\Delta\lambda m$ of a Fabry-Perot mode.



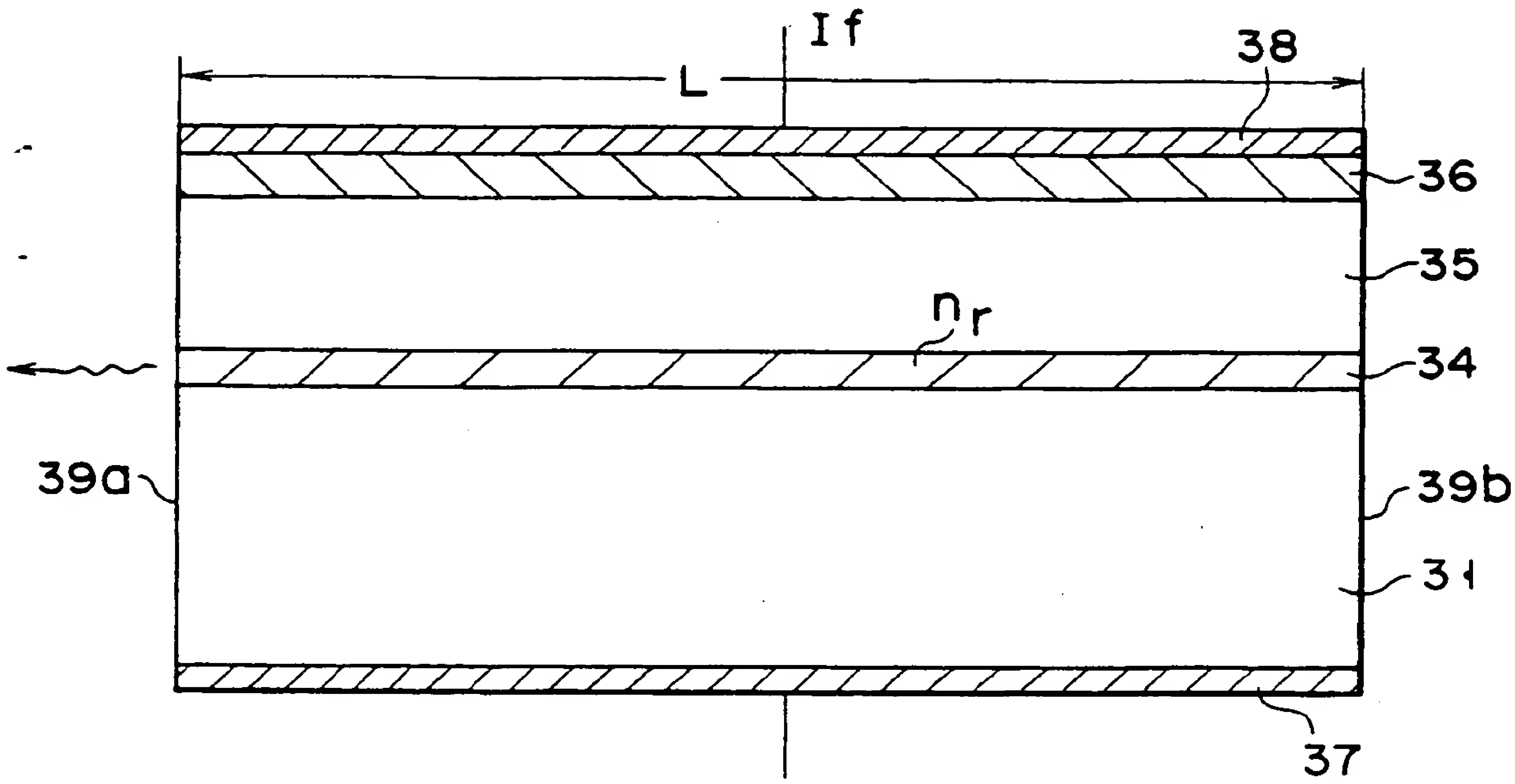
F I G. 1



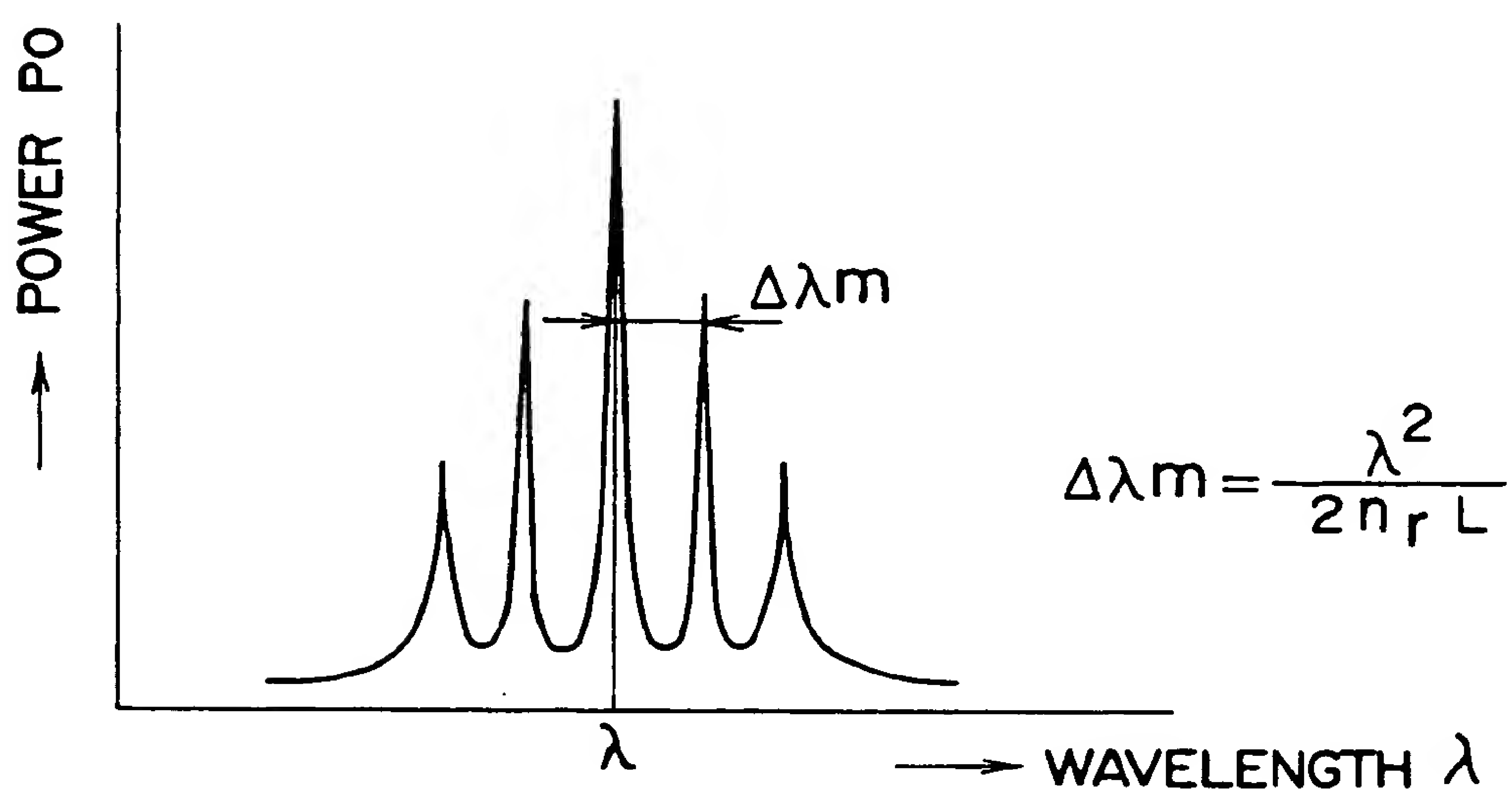
F I G. 2



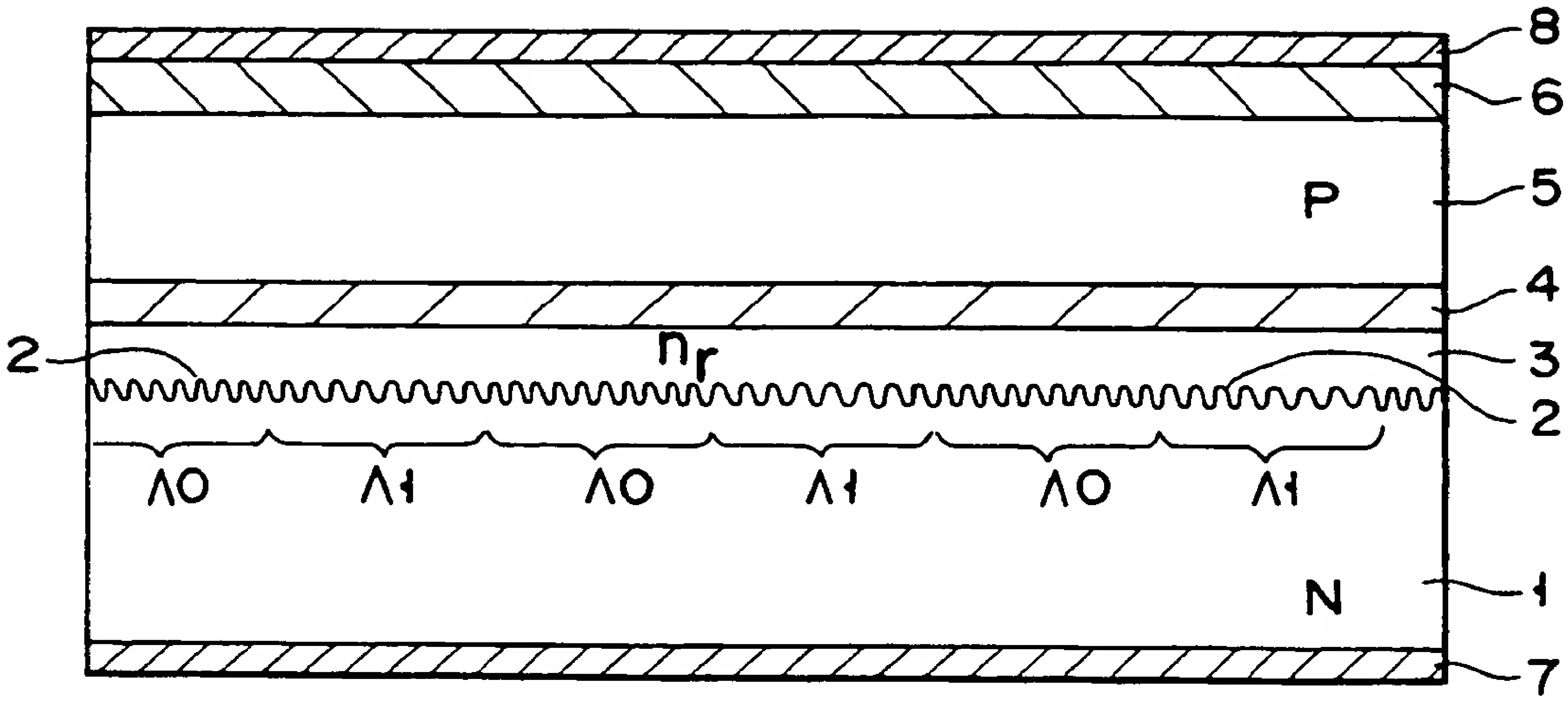
F I G. 3


If
L
38
36
35
n_r
34
39a
39b
31
37

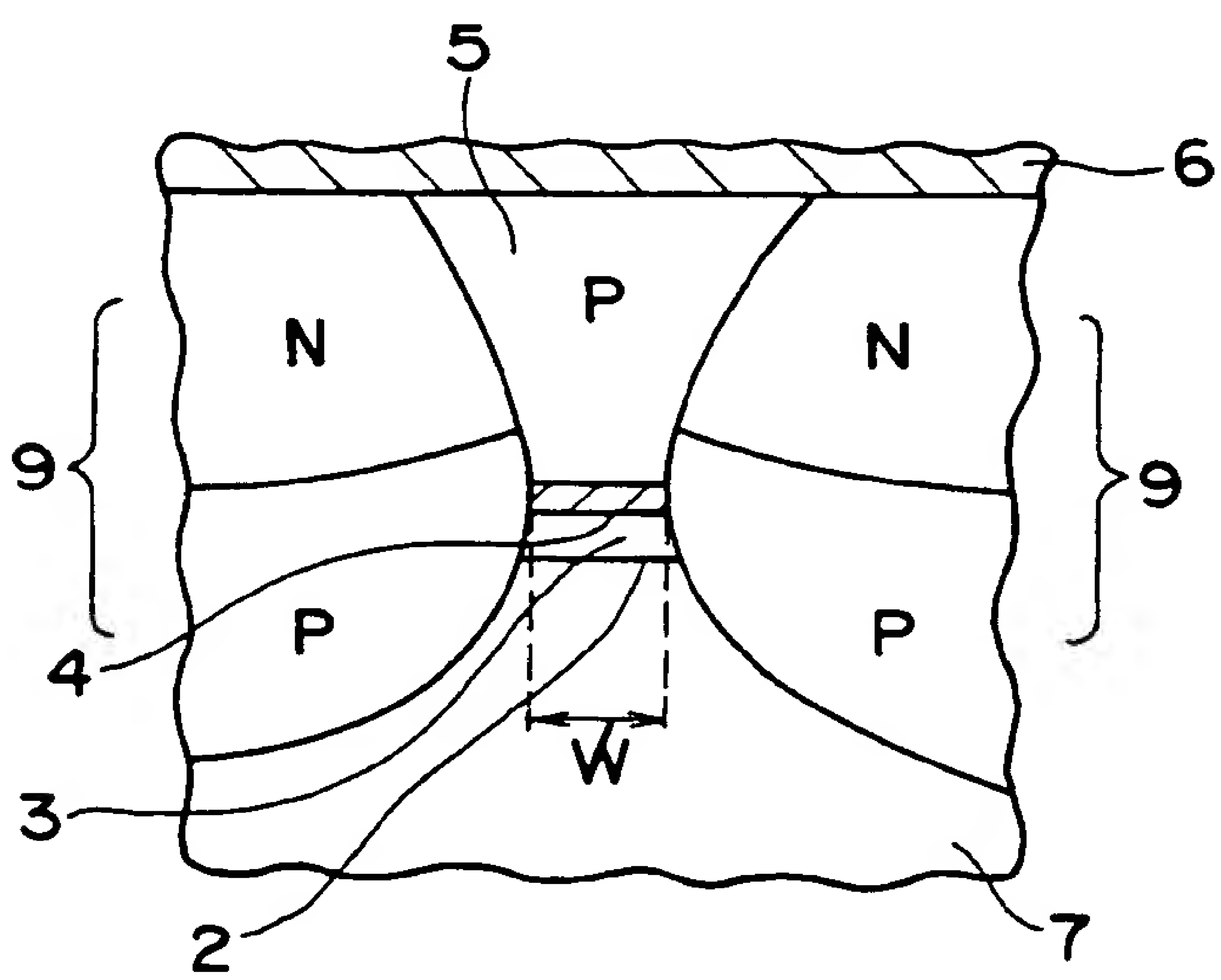
F I G. 4


POWER Po
$\Delta\lambda m$
$\Delta\lambda m = \frac{\lambda^2}{2 n_r L}$
λ
WAVELENGTH λ

F I G. 5



F I G. 6



F I G. 7

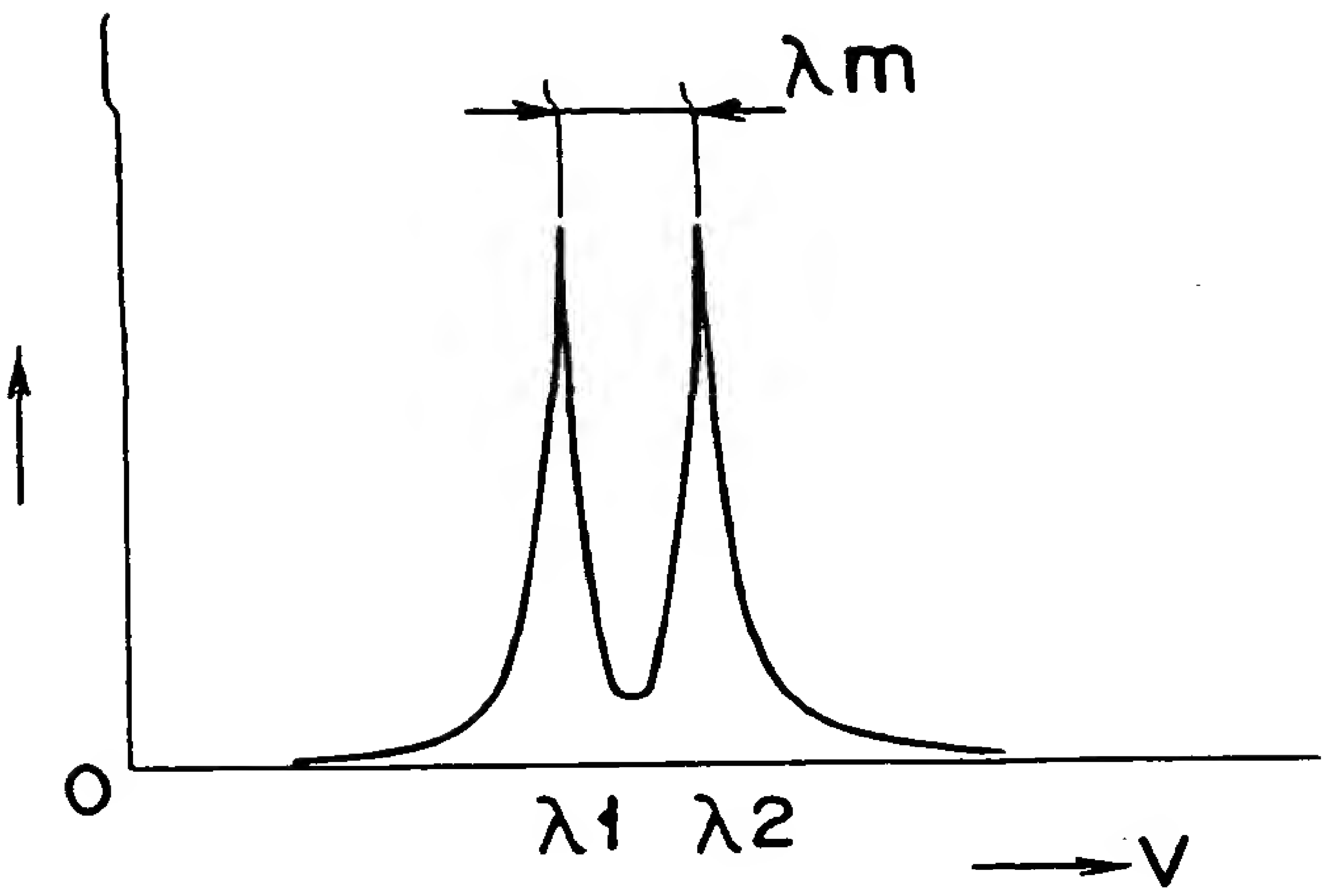


FIG. 8

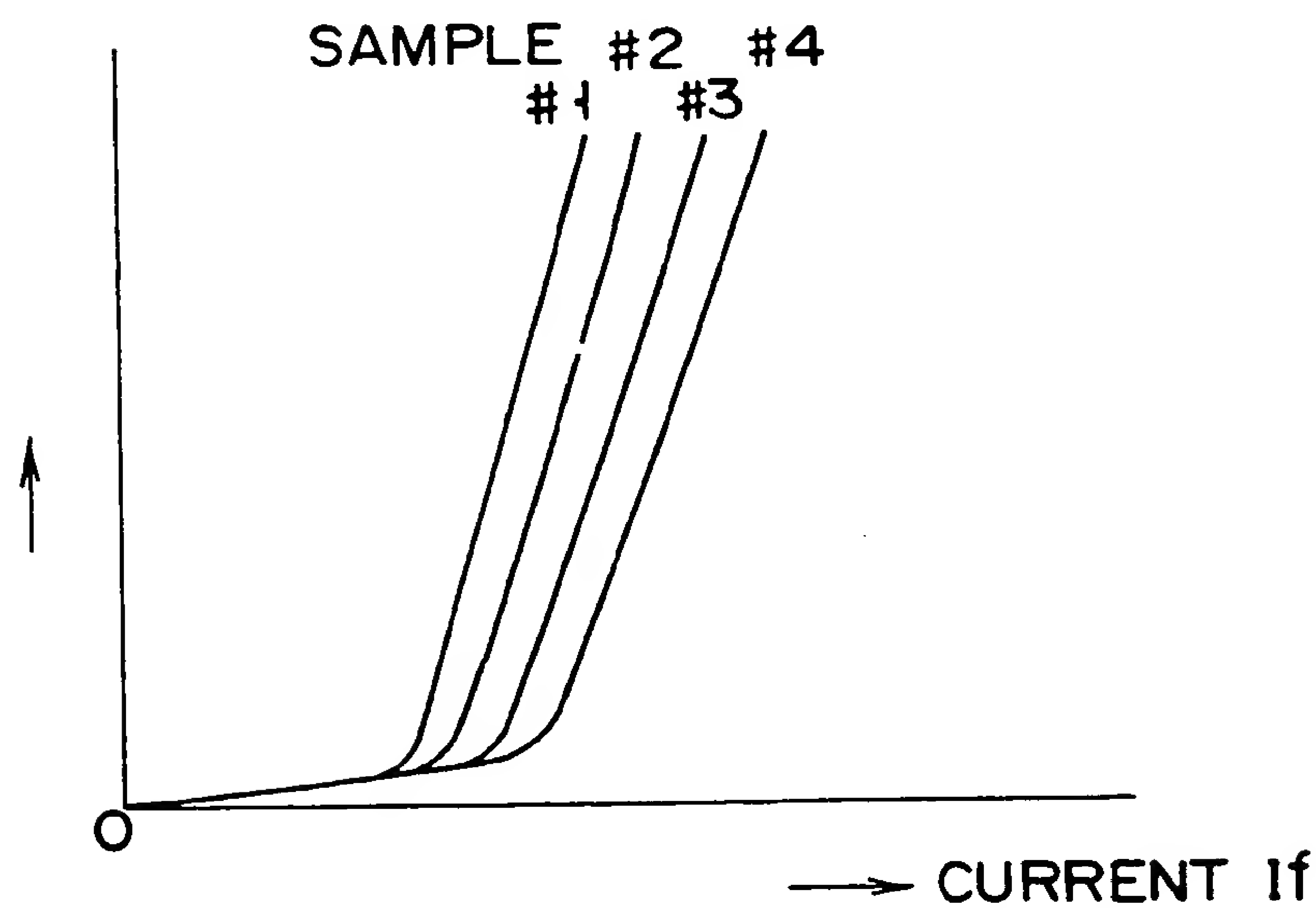
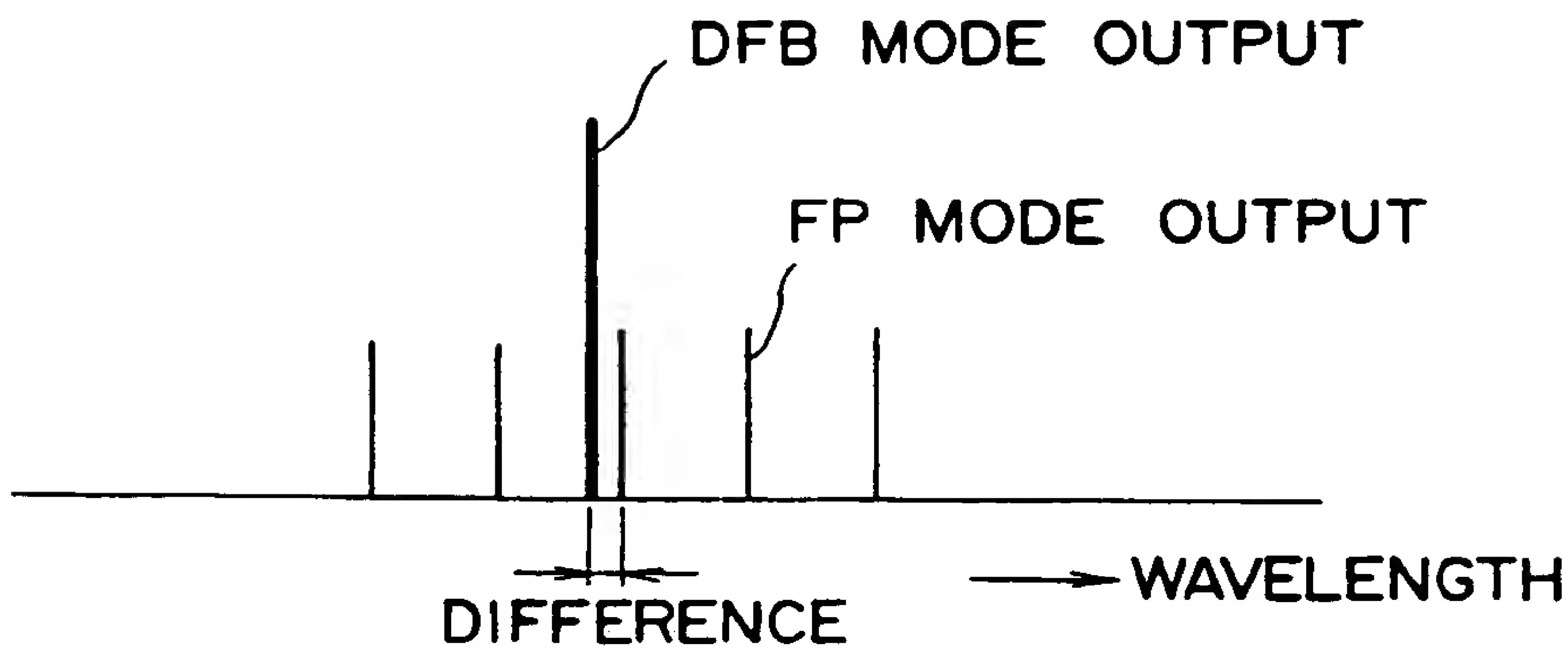
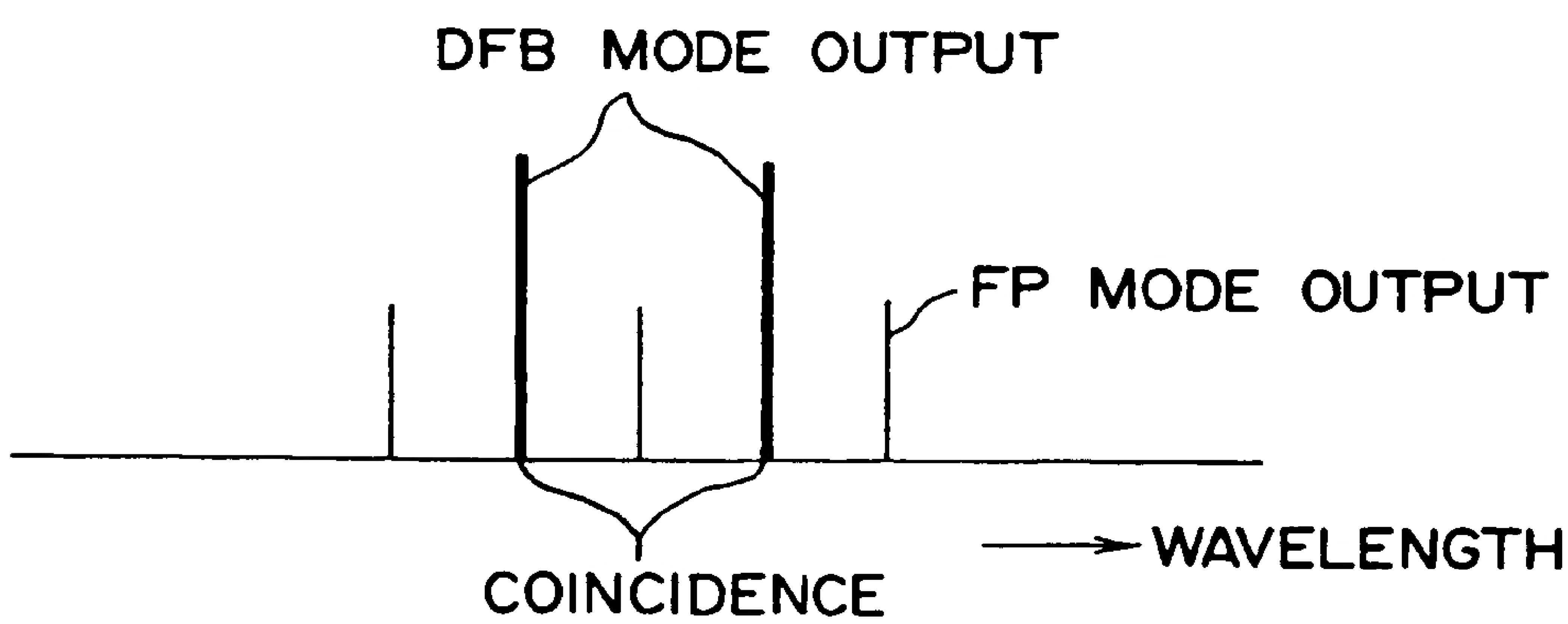


FIG. 9



F I G. 10A



F I G. 10B

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(88) Date of deferred publication of the search report: **30.09.92 Bulletin 92/40**

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(54) **Distributed feedback semiconductor laser.**

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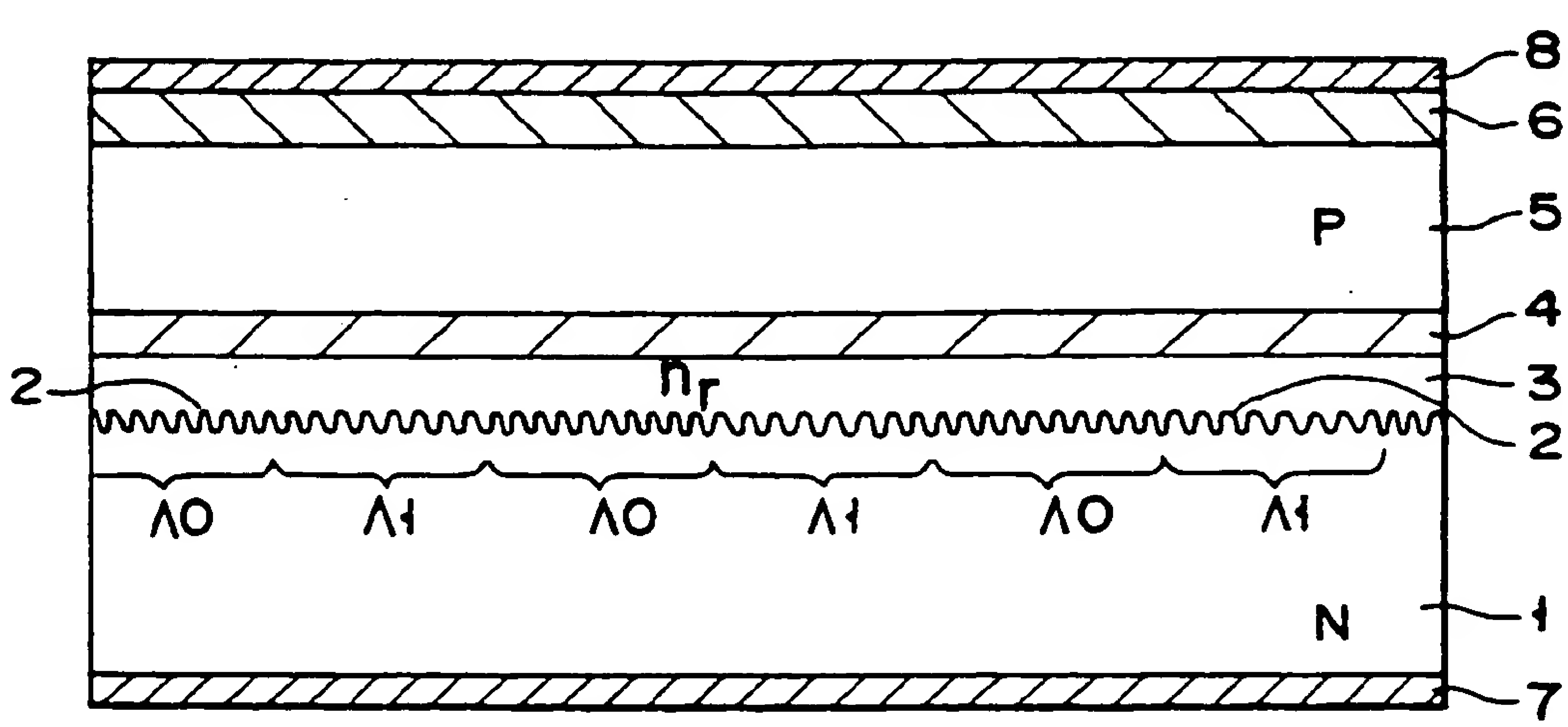

F I G. 6

EP 0 479 279 A3

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EUROPEAN SEARCH REPORT

Application Number

EP 91 11 6846

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X A	US-A-4 775 980 (NAOKI CHINONE) * Abstract; figures 1,2,5; column 1, line 32 - column 2, line 7; column 3, lines 40-56; claims 1,2 * ---	1 3	H 01 S 3/085
X A	JP-A-2 234 485 (CANON INC.) * Whole document * & PATENT ABSTRACTS OF JAPAN, vol. 14, no. 550 (E-1009), 6th December 1990 ---	1 3	
P,X	PATENT ABSTRACTS OF JAPAN, vol. 15, no. 379 (E-1115), 25th September 1991; & JP-A-3 150 890 (HITACHI) 27-06-1991 * Whole document * ---	1	
A	PATENT ABSTRACTS OF JAPAN, vol. 11, no. 108 (E-495)[2555], 4th April 1987; & JP-A-61 255 087 (MITSUBISHI ELECTRIC CORP.) 12-11-1986 * Whole document * ---	1,3	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
A	JOURNAL OF APPLIED PHYSICS, vol. 63, no. 2, 15th January 1988, pages 291-294, Woodbury, NY, US; M.C. WU et al.: "Wavelength tuning and switching of a coupled distributed feedback and Fabry-Perot cavity laser" * Whole document * --- -/-	2,3	H 01 S

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	20-07-1992	CLAESSEN L.M.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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Office

EP 91 11 6846

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

☐ All claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for all claims.

☐ Only part of the claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid,

namely claims:

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions,
namely:

See sheet -B-

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid,

namely claims:

☐ None of the further search fees has been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims.

namely claims:

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91 11 6846

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	JOURNAL OF LIGHTWAVE TECHNOLOGY, vol. 8, no. 3, March 1990, pages 274-293, IEEE, New York, US; T.L. KOCH et al.: "Semiconductor lasers for coherent optical fiber communications" * Chapter I, paragraph B; chapter II, paragraph A * ---	2	
A	ARCHIV FÜR ELEKTRONIK & ÜBERTRAGUNGSTECHNIK, vol. 41, no. 1, January/February 1987, pages 1-9, Stuttgart, Germany; A.P. MOZER et al.: "Herstellung und Eigenschaften von 1,3Mum-Dauerstrich-Single-Mode-Lasern" * Chapter 2 * ---	2	
A	US-A-4 786 132 (GORDON) * Abstract; column 6, lines 11-62 * ---	2	
A	IEEE JOURNAL OF QUANTUM ELECTRONICS, vol. QE-20, no. 3, March 1984, pages 236-245, New York, US; K. UTAKA et al.: "Effect of mirror facets on lasing characteristics of distributed feedback InGaAsP/InP laser diodes at 1.5 Mum range" * Abstract; chapter IV, paragraph C * ---	2	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
A	JOURNAL OF LIGHTWAVE TECHNOLOGY, vol. LT-4, no. 10, October 1986, pages 1454-1459, IEEE; M. YANO et al.: "Extremely low-noise facet-reflectivity-controlled InGaAsP distributed-feedback lasers" * Abstract; introduction; discussion * -----	2	

The present search report has been drawn up for all claims

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THE HAGUE	20-07-1992	CLAESSEN L.M.

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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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EP 91 11 6846 -B-

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims 1,3: A distributed feedback laser having a grating containing a plurality of different pitches

2. Claim 2: A distributed feedback laser having a grating with a pitch corresponding to Fabry-Perot oscillation modes